Sustained parasiticide use in cattle farming affects dung beetle functional assemblages

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Abstract

In pastoral agricultural landscapes, dung beetles provide important ecosystem functions including the removal of standing livestock dung, increasing pasture fertility and reducing parasite transmission. Faecal residues of the macrocyclic lactones (MLs) and synthetic pyrethroids (SPs) commonly used to treat livestock against endo- or ectoparasites (parasiticides), can have negative impacts on invertebrates such as dung inhabiting beetles. However, the extent of any functional ecological impact from their sustained use is unclear. The current work aimed to quantify the landscape-level effects on dung inhabiting beetle species assemblages associated with sustained parasiticide use within different farming systems. Cow dung-baited pitfall trapping was undertaken on 24 beef cattle farms in SW England, which either used MLs (n=8), SPs (n=7) or no parasiticides (n=9). There were no differences in overall beetle abundance between farm types, however species richness, diversity, and functional diversity were higher on farms with a history of using no parasiticides compared to farms that used parasiticides. Species of endocoprid (dung dwelling) beetle dominated the community on farms that used parasiticides, particularly MLs, while paracoprid (dung burying) beetles were rare, possibly due to differential impacts depending on life history traits of the functional groups. The results are of concern because the long-term loss of dung beetle diversity and changes in functional assemblages have the potential to impair ecosystem function in agricultural landscapes.

Keywords

Diversity, dung beetle, ecosystem function, parasiticide, macrocyclic lactone, pyrethroid

1. Introduction

Livestock farming in the United Kingdom (UK) commonly uses a range of systemic macrocyclic lactone (ML) compounds to treat cattle against endoparasites (worms and fluke) while topical insecticides, such as synthetic pyrethroids (SPs), are more commonly used against ectoparasites (ticks and lice) and biting flies (AHDB, 2017). Macrocyclic lactones activate invertebrate-specific glutamate-gated chloride channels resulting in paralysis and death (Bloomquist, 1996). Pyrethroids are also neurotoxic to insects and prevent the closure of axonal sodium channels (Casida et al. 1983). However, residues of these compounds are known to be excreted largely unmetabolized in cattle faeces for approximately 1-4 weeks after treatment, where they continue to have insecticidal effects via the mechanisms described above (Herd et al., 1996; Sommer et al., 1992; Vale et al., 2004; Wardhaugh et al., 1998). The negative impacts that these residues have on invertebrates, for example dung colonizing beetles, is well documented, for both MLs (e.g. Beynon et al., 2012a,b; Strong et al., 1996; Wall and Strong, 1987) and SPs (Bang et al., 2007; Vale et al., 2004; Wardhaugh et al., 1998).

Dung colonizing beetles provide important ecosystem functions in agricultural landscapes including the removal of standing dung from pastures (Beynon et al., 2012b, Holter 1979), bioturbation (Mittal, 1993), nutrient cycling (Doube, 2008), and parasite control (Sands and Wall, 2016). Dung breakdown and incorporation into the earth is essential in nutrient cycling and the return of nutrient rich organic matter back into the soil (Yoshitake et al., 2014). Work in Australia has shown that cattle dung burial by the paracoprid beetle *Bubas bison* (Linnaeus 1767) resulted in elevated levels of nitrate, ammonia, phosphate, sulphur and carbon in soil, as well as increased soil organic matter and increased pH, for at least two years after the burial event (Doube, 2008). Beetle activity in faeces may make the environment unfavourable for the survival and development of the free-living stages of gastro-intestinal parasites of livestock, which develop in dung pats (Sands and Wall, 2016). Studies have demonstrated a reduction in parasite larval recovery from pasture herbage when dung was colonised by dung beetles compared to uncolonized dung (English, 1979; Sands and Wall, 2016). Current estimates place the economic value of dung beetles to the UK cattle industry at £367 million per year, largely due to the cost of parasite control (Beynon et al., 2015). Any reduction in the abundance or diversity of dung beetles, due to sustained effects of treatment with parasiticides (endo- and/or ecto- parasiticidal veterinary treatments) (Hutton and Giller, 2003), may therefore result in reduced ecosystem function and production losses in agricultural systems (Manning et al., 2016; Tixier et al., 2015).

Pasture-level experimental studies have suggested decreased species richness and diversity for a number of dung inhabiting taxa after treatment with ivermectin (MK-0933, 22, 23-dihydroavermectin B1; a macrocyclic lactone antiparasiticide derived from the bacterium *Streptomyces avermitilis* (Chhaiya et al. 2012)) (Jochman and Blanckenhorn, 2016; Krüger and Scholtz, 1998a). There were significant reductions in the abundance of 12 out of 32 hymenopteran and dipteran taxa collected from ivermectin-treated dung compared to control dung (Jochman and Blanckenhorn, 2016). Species specific effects of ivermectin residues on dung inhabiting beetles have also been reported, with significantly reduced adult survival and offspring emergence in two and four out of nine dung beetle species respectively (Beynon et al. 2012b). Studies comparing different farming systems found higher dung insect abundance and diversity on organic farms, where veterinary parasiticides are not used intensively, compared to rough grazing or intensive farms (Hutton and Giller, 2003), and on nature conservation areas and organic farms than conventionally managed farms (Geiger et al., 2010).

The extent of any sustained ecological impact on dung beetle assemblage structure resulting from the toxic effects of veterinary parasiticides reported in experimental studies remains unclear (Wall and Beynon, 2011). Recent experimental work has suggested no evidence of any persistent impact of anthelmintic exposure on ecosystem multifunctionality (Manning et al., 2017). However, landscape level studies that consider entire dung beetle communities are lacking. The aim of the current work was therefore to quantify the sustained effects of chemical residues in cattle dung on dung colonizing beetle communities as a result of long-term parasiticide use within farming systems, via a landscape-level study examining species abundance, richness, diversity and functional diversity. Dung beetles, *sensu stricto*, are represented by the families Scarabaeidae and Geotrupidae, and include species of *Geotrupes, Onthophagus* and *Aphodius* in temperate climates (Skidmore, 1991). However, other beetles, including those in the families Histeridae, Hydrophilidae and Staphylinidae also live and feed in dung, for example the coprophagous hydrophilid *Sphaeridium lunatum* (Fabricius 1792) has been shown to have similar morphological adaptations of its mouthparts for dung feeding as coprophagous Scarabaeidae species (Holter, 2004). Little is known about the contribution of these latter beetle families to the dung invertebrate community or the process of dung decomposition, but due to their high abundance in temperate cattle dung pats their role may merit further study. As a result, this study refers to two subsets of beetles, the 'dung beetles proper' (Scarabaeidae and Geotrupidae), and 'all dung inhabiting Coleoptera' (also including Hydrophilidae, Histeridae and Staphylinidae).

2. Methods

2.1 Study sites

Twenty-four beef farms located across SW England were chosen as study sites, 12 were registered organic and 12 were conventionally managed. Within these two broad categories, farms represented a range of different parasiticide use practices, size and terrain (hill, upland and lowland). Based on their history of parasiticide use the farms fell into three categories: farms that used no SPs or MLs (n=8), farms that used SPs only (n=7) and farms that used MLs only (n=9). None of the organic farms treated with MLs, however six used SPs. Nine of the farms that were not registered as organic used MLs, while one used SPs and two used no parasiticides. To qualify for inclusion in this study, farms must have been operating under the same management practices for at least the previous 3 years. Complete information regarding key farm variables can be found in Table. 1.

2.2 Pitfall trapping

Pitfall trapping was carried out in 2016 during early summer (13^{th} June – 26^{th} July) on all 24 farms, and late summer (15^{th} August – 8^{th} September) on 16 of the farms. Each organic farm was paired with its most proximate conventional farm and trapping was performed on the two paired farms simultaneously to control for any climatic variation between trapping days. At each farm, 10 cow-dung baited pitfall traps were set up between 09:00 and 12:00 h, 5 m apart, along a straight transect within 50 m of grazing beef cattle but separated from the herd by a fence to prevent trampling. One organic farm was removed from the study at an early stage because its cattle were allowed to roam across moorland so it could not be guaranteed that pitfall traps were within 50 m of the herd. Pitfall traps consisted of plastic buckets (18 cm diameter x 16 cm depth) that were buried flush with the ground, half filled with water to which 1 ml of detergent was added, and covered with wire mesh with a 2x2 cm grid. Freshly voided cattle dung collected from the organic farm in each pair was homogenised and used for both farms of the pair, to prevent differences in attractiveness due to variation in dung chemical parameters. Dung was placed on the wire mesh using a 20 cm diameter pat former that held 800 g faeces, and a rain guard was positioned at a height of 20 cm to prevent flooding. Beetles attracted to the dung entered the pat and fell through the wire mesh into the bucket below. The traps were left for 24 h before beetles were collected and stored in ethanol. All Coleoptera trapped were counted, and identified using Jessop (1986) and Skidmore (1991).

2.3 Data analysis

For the purpose of this study, analysis was applied to two groups; the dung beetles proper (families Scarabaeidae and Geotrupidae), and all dung inhabiting Coleoptera, which also included beetles in the families Hydrophilidae, Histeridae and Staphylinidae. To compare species assemblages between the three farm types (farms that used no parasiticides, SPs-only, or MLs-only), rank/abundance distributions were plotted based on the number of dung inhabiting coleopteran species and their relative abundances. A detrended correspondence analysis (DCA) was performed on proportional species abundance between farms, to compare dung beetle assemblage similarity. DCA is a community ordination technique, which can be used to analyse community composition data, look at similarities between sites and identify characteristic species in each community (Magurran, 1988). It produces a graph whereby similar objects are ordinated near each other (Janžekovič and Novak, 2012), and was included in this study in order to examine similarities in dung beetle assemblage structure across the three farm types.

Communities were described by total abundance, number of taxa (richness), and two measures of biodiversity: the Shannon diversity index H' and the Simpson dominance index D (Magurran, 1988; Shannon, 1948; Simpson, 1949). These biodiversity measures were chosen because they can provide important information about community composition. For example, the Shannon diversity index H' is based on the proportional abundances of species, taking evenness and species richness into account, and represents the uncertainty about the identity of an unknown individual (Morris et al., 2014; Magurran 1988). The Simpson dominance index D is less sensitive to species richness but is weighted towards the abundances of the commonest species, providing information on the degree to which single species dominate the community. It represents the probability that two randomly chosen individuals belong to different species (Morris et al., 2014; Magurran 1988). They are calculated from the equations: $H' = - \Sigma (n_i/N \ \ln (n_i/N))$ and $D = \Sigma (n_i(n_i - 1)/N(N - 1))$ respectively, where n_i is the number of individuals found in the ith species and N is the total number of individuals. It must be noted that these indices are representative of a sample therefore fail to include all species from the community (Magurran, 1988). Analysis of these measures was applied to the dung inhabiting Scarabaeidae and Geotrupidae in the first instance and then to all dung inhabiting Coleoptera. Finally, functional assemblages of the Scarabaeidae and Geotrupidae were examined based on the number of individuals belonging to paracoprid (dung burying) or endocoprid (dung dwelling) functional groups.

All statistical analysis was performed using RStudio (Version 1.0.44, RStudio Team, 2016). A generalized linear model with a negative binomial error distribution was used to analyse count data of species abundance, including the following farm variables (Table 1) as explanatory variables: ‘parasiticide use’, ‘years farmed’, ‘participation in agri-environment scheme’, ‘area of grazed land (m^2)’, ‘terrain’, ‘number of head of cattle’, ‘grazed with sheep’ and ‘season’. These were included in the model because their potential effects on the dependent variable were of interest. A generalized linear model with a Poisson error distribution was used with species richness as the response variable and the above explanatory farm variables. For the biodiversity indices of species diversity H’ and species dominance D, a generalized linear model with a Gaussian error distribution was performed with above explanatory farm variables. The analyses were performed separately for the dung beetles proper and then for all dung inhabiting Coleoptera. If season was a significant factor, data from early summer and late summer were analysed separately. Models were simplified by stepwise removal of non-significant factors and the resulting minimal model contrasted with Akaike's Information Criterion (AIC) to the global model, until the best fitting model was found (Bozdogan, 1987). Analysis was also carried out as described above for the farm variable 'number of years organic' replacing 'parasiticide use', due to non-independence of these variables.

Pearson's Chi-Square Test (which evaluates whether two categorical variables, i.e. dung beetle functional group and farm type, are associated) was applied to count data on the number of dung beetles belonging to either the paracoprid or endocoprid functional groups retrieved from each of the three farm types. Post-hoc analysis was performed using the package 'fifer', with Bonferroni adjustments to the P-values to account for inflation due to multiple comparisons.

3. Results

3.1 Dung beetle community assemblages

Over the duration of the study, a total of 42,509 beetles were collected from the pitfall traps. Of these, 11,810 were dung colonizing beetles belonging to the families Scarabaeidae and Geotrupidae, representing 24 different species. The remainder were beetles in the families Hydrophilidae (20,987), Histeridae (106) and Staphylinidae (9,606). Of the dung beetles proper, those in the subfamily Aphodiinae were the most dominant comprising 81.3% of the dung beetles collected. *Onthophagus* spp. (Subfamily: Scarabaeinae) made up 18.3% and the remaining 0.4% were *Geotrupes* spp. The most abundant dung beetle species was *Aphodius (Acrossus) rufipes* (Linnaeus, 1758) which comprised 70.6% alone. Overall, seven dung beetle species (*A. A. rufipes, Onthophagus coenobita* (Herbst, 1783)*, Onthophagus similis* (Scriba, 1790)*, Aphodius (Agrilinus) rufus* (Moll, 1782)*, Aphodius (Colobopterus) erraticus* (Linnaeus, 1975)*, Aphodius (Aphodius) fimetarius* (Linnaeus, 1758)*, Aphodius (Teuchestes) fossor* (Linnaeus, 1758)) accounted for 97.3% of those trapped, but their relative abundance varied between farm management type (Table 2).

Paracoprid beetles (dung burying beetles), such as those in the genus *Onthophagus* comprised just 1% of the total dung beetles trapped on farms that used MLs, compared to 19% and 41% on farms that used SPs and farms that used no parasiticides, respectively. There were eight rare species, (*Aphodius (Aphodius) foetidus* (Herbst, 1783)*, Aphodius (Otophorus) haemorrhoidalis* (Linnaeus, 1758)*, Aphodius (Melinopterus) punctatosulctatus* (Sturm 1805)*, Aphodius (Nimbus) contaminatus* (Herbst, 1783)*, Aphodius (Planolinus) borealis* (Gyllenhal, 1827)*, Aphodius (Acrossus) luridus* (Fabricius, 1775)*, Onthophagus joannae* (Goljan, 1953)*, Onthophagus fracticornis* (Preyssler, 1790)) which combined, comprised just 0.14% of the dung beetles collected.

Rank abundance distributions of beetle assemblages for all three farm types approached Motomura's geometric model (Motomura, 1932), implying uneven communities with high dominance of a few abundant species (Heip et al., 1998) (Fig.1). Community ordination also suggested that there were relatively similar assemblages of the dung beetles proper on the three farm types, since there was no major separation of farm types across the axes (Fig. 2).

3.2 Season

There was a significantly greater abundance of all dung inhabiting Coleoptera (Z_{26}=2.78, P=0.005) and of the dung beetles proper (Z_{26}=4.37 P<0.001) captured in late summer than in early summer (Fig. 3a). Dung beetle species diversity, measured by the Shannon diversity index, was significantly higher in early summer than late summer (t_{14}= -3.40, P=0.004) (Fig. 3b). Species richness was not significantly different between early and late summer for the dung beetles proper or for all the dung inhabiting Coleoptera. As a result, the data for the two collection periods are treated separately for analyses of abundance and diversity, but not richness.

3.3. Abundance

In early summer, there were no significant differences in abundance between the farms that used MLs, SPs or no parasiticides for the dung beetles proper or for all dung inhabiting Coleoptera. In late summer (the time of higher abundance) there were significantly fewer dung beetles on farms that used SPs than farms that used MLs (Z_{11}=-2.35, P = 0.02), but there were no significant differences between farms that used no parasiticides and farms that used MLs or SPs. There were no significant differences in abundance of all dung inhabiting Coleoptera between farms that used MLs, SPs, or no parasiticides in late summer.

In late summer, there were also significantly greater numbers of dung beetles captured on farms that participated in agri-environment schemes than those that did not (Z_{11}=2.65, P = 0.008). None of the other farm variables had significant effects on abundance, and so were removed from the model during stepwise simplification, as described above.

3.4 Species richness

Species richness of the dung beetles proper was significantly lower, by approximately 34%, on farms that used MLs compared to farms that used SPs (Z_{35}=2.31, P=0.02), and similarly the richness of all dung inhabiting Coleoptera was significantly lower, by approximately 23%, on farms that used MLs compared to farms that used SPs (Z_{35}=2.11, P=0.03) (Fig. 4). Species richness was approximately 19% and 13% lower on farms that used no parasiticides compared to farms that used MLs, for the dung beetles proper and for all dung inhabiting Coleoptera respectively (Fig. 4). None of the other farm variables had significant effects on species richness, and so were removed from the model during stepwise simplification, as described above.

3.5 Species diversity

In early summer, there were no differences in the species diversity of the dung beetles proper between farms that used SPs, MLs or no parasiticides, however in late summer there was significantly lower diversity, by approximately 63%, on farms that used MLs than those that used SPs (t_{12}=2.58, P=0.024) (Fig. 5a). Diversity of dung beetles proper was approximately 34% lower on farms that used MLs compared to those that used no parasiticides. Diversity of all dung inhabiting Coleoptera was also significantly lower on farms that used MLs than on farms that used no parasiticides (by 17%) (t_{35}=2.47, P=0.018) and farms that used SPs (by 28%) (t_{35}=3.11, P=0.004) (Fig. 5a). None of the other farm variables had significant effects on species diversity, and were removed from the model during stepwise simplification, as described above.

3.6 Species dominance

In early summer there were no differences in species dominance of the dung beetles proper between farms that used SPs, MLs or no parasiticides, however in late summer species dominance was significantly higher, by approximately 60%, on farms that used MLs than farms that used SPs (t_{12}=-2.31, P=0.04) (Fig. 5b). Species dominance of the dung beetles proper was approximately 16% higher on farms that used MLs compared to farms that used no parasiticides. Species dominance of all dung inhabiting Coleoptera was significantly higher on farms that used MLs compared to farms that used SPs (by 52%) (t_{35}= -2.95, P=0.005) and farms that used no parasiticides (by 19%) (t_{35}= -2.46, P=0.019) (Fig. 5b). None of the other farm variables had significant effects on species dominance, are were removed from the model during stepwise simplification, as described above.

3.7 Dung beetle functional groups

For the dung beetles proper, there was a significant association between parasiticide use and functional group (χ^2= 2084, P<0.001); farms that used parasiticides had fewer paracoprids than farms that did not. There were significant differences in functional assemblages between communities of dung beetles on farms that used MLs compared to farms that used SPs (P<0.001) or no parasiticides (P<0.001), and between farms that used SPs compared to farms that used no parasiticides (P<0.001) (Fig. 6). The ratio of paracoprid:endocoprid dung beetles was 1:99 on farms that used MLs, 1:4.3 on farms that used SPs and 1:1.4 on farms that used no parasiticides.

3.8 Organic farms

Of the 11 organic farms, there was a significant positive linear relationship between the number of years the farm had been organic, and the abundance of dung inhabiting Coleoptera ($F_{1,22}$=5.30, P=0.03, R^2=0.19). On these farms there was also a significant positive linear relationship between the area of grazed land (m^2), and the species richness of both the dung beetles proper ($F_{3,20}$=4.44, P=0.002, R^2=0.37) and all dung inhabiting Coleoptera ($F_{3,20}$=7.35, P<0.001, R^2=0.49). Species richness of the dung beetles proper (t_{20}=2.44, P=0.02) and all dung inhabiting Coleoptera (t_{20}=3.48, P=0.002) was significantly higher on lowland farms than on hill farms.

4. Discussion

The impacts of pesticides and parasiticides on dung colonizing insect diversity and community function in farmland ecosystems have proved challenging to study at a landscape level, because such inherently complex systems require large-scale and long-term studies to detect intrinsic patterns (Wall and Beynon, 2012). Here, the 24 beef farms visited represented a broad range of approaches to parasiticide use, grouped into three strategies: those that treated cattle with macrocyclic lactones only (MLs), all of which were conventionally managed, or those that treated with synthetic pyrethroids only (SPs) and those that used no parasiticides, 12 of which were registered as organic. Farms had followed the same parasiticide use pattern for at least three years prior to the study. Dung from each organic farm was used to bait pit-fall traps on the farm where it was collected and its paired conventional farm; this therefore makes the assumption that the dung from these farms was equally attractive. This was done to minimize potential differences in the beetle assemblages that would be attracted to the traps, as it has been suggested that dung containing ivermectin residues may be more attractive to temperate dung beetles than dung from untreated cattle (Errouissi and Lumaret, 2010).

Rank abundance curves displayed a geometric series model, which suggests that the communities of dung inhabiting beetles are dominated by a small number of highly abundant species on all three farm types (Motomura, 1932). This is demonstrated by the fact that a single species, *A. A rufipes* alone, comprised 70.6% of all the dung beetles captured, seven species accounted for 97.3%, and eight of the least abundant species accounted for just 0.14% of those trapped. This is typical of temperate dung beetle assemblages, which have been shown to be dominated by small numbers of species that represent 70-95% of the abundance (Kadiri et al., 2014). A steeper rank abundance slope indicates that a small number of species are able to dominate the resource, and Motomura's model suggests that that this may be caused by an environmental constraint, such as provided here by parasiticides in the dung. The environmental constraint results in higher structuring through increased dominance leading to reduced diversity (Labidi et al., 2012). Here, the rank-abundance curve for farms that used MLs lay slightly below, and was truncated, compared to the other farms, suggesting that there were fewer species present.

In the present study, and observed by Beynon et al. (2012b) in a mesocosm study, impacts appeared to vary between functional groups, with paracoprid (dung burying) beetles such as those in the genus *Onthophagus* being less abundant, and endocoprid (dung dwelling beetles) such as *A. A. rufipes* dominating the community on farms that used parasiticides. The cause of this effect cannot be determined from the data collected, however paracoprid beetles (K-type life history species) have lower fecundity compared to endocoprids (r-type life history species) (Hanski and Cambefort, 1991), so their populations may be less able to recover after parasiticide exposure. Physiological mechanisms such as sequestration, excretion or target site sensitivity (Cabrera et al., 2017) may also affect sensitivity to insecticide residue, however further ecotoxicity studies comparing functional groups are needed to confirm this.

In early summer, the diversity of all dung inhabiting beetles was significantly higher overall compared to late summer and there were no differences in diversity or dominance between farm types. By late summer, the diversity of all dung inhabiting beetle species was higher on farms that used no parasiticides than farms that used MLs, and also higher on farms that used SPs than on farms that used MLs. Beetle species dominance was higher on farms that used MLs than SPs, and on farms that used SPs than no parasiticides. Dung beetle assemblages on farms that used SPs showed no alterations to diversity or dominance compared to farms that used no insecticides. Hutton and Giller (2003) reported reduced numbers of *Aphodius* spp. in autumn on intensive farms that applied ivermectin in spring compared to organic sites, and clear separation in community ordination in late summer and autumn between farms that applied ivermectin and farms that did not. They explained this in terms of a modelling study, which predicted that treatment with the ML eprinomectin could reduce activity of *Onthophagus taurus* (Schreber, 1759) in the next generation by 25-35% (Wardhaugh et al., 2001). The reduced diversity in late summer on farms that used MLs in the present study may therefore be a result of reduced survival of second generation beetles within the season. A field study during a

South African drought, sampled dung pats from two paddocks containing beef herds that had received a standard injection of the ML ivermectin, and found that ivermectin affected the dung insect community for three months after treatment, also by decreasing species diversity (measured by the Shannon index H') and evenness (measured by Pielou's J' evenness), compared to two control paddocks containing untreated cattle (Krüger and Scholtz, 1998a). No such impacts of ivermectin were seen when the study was conducted under high-rainfall conditions, suggesting that the effects of ivermectin on dung beetle diversity measures may be compounded under environmental stress such as drought (Krüger and Scholtz, 1998b). A landscape-scale study, conducted on 24 Swiss farms, found significantly reduced emergence in 12 out of 32 dipteran and hymenopteran taxa from dung spiked with ivermectin, compared to parasiticide-free control dung, again resulting in strongly reduced biodiversity (Jochmann and Blanckenhorn, 2016). Of the total dung inhabiting Coleoptera collected in the present study, 49% were Hydrophilidae and 23% were Staphylinidae. Although there is little known about their contribution to the dung invertebrate community or process of decomposition, their abundance suggests that their role, for example in pat aeration, would merit further study.

The data presented here suggest that both ML and SP use had significant impacts on dung beetle functional diversity; there were significant differences in the proportions of beetles belonging to different functional groups, with paracoprid (dung burying) beetles such as those in the genus *Onthophagus*, being less abundant and endocoprid (dung dwelling beetles), such as *A. A. rufipes,* dominating the community on farms that used parasiticides. Currently organic farms may use SPs to treat for pests and ectoparasites such as flies, ticks and lice, and the current data suggest that SPs appear to have less impact than MLs. Beynon et al. (2012b) added a set biomass of dung beetles to mesocosms containing 600 g cattle dung, varying species richness of three functional groups - dung-ovipositing endocoprids, soil-ovipositing endocoprids and paracoprids. After 4 weeks they found that paracoprid beetles contributed more to dung decomposition than endocoprids, with faster decomposition rates for paracoprids than either endocoprid group (Beynon et al., 2012b). Additionally, tunneling by paracoprid beetles has been shown to improve the physiochemical characteristics of soil and increase feed value of the herbage, by incorporating organic matter into the soil (Bang et al., 2005). The association seen here between parasiticide use and beetle community structure might therefore be expected to have some effect on ecosystem function. However, such impacts are complex, difficult to identify and the subject of some debate. The negative effects of ML use on dung beetle species richness and diversity were not observed with SP use, and generally farms that used SPs had similar dung beetle diversity to farms that did not use parasiticides.

Beynon et al. (2012b), using mesocosm experiments, suggested that species-rich dung beetle communities buffer the ecosystem service of dung decomposition under anthropogenic perturbations such as ivermectin treatment. The dung decomposition rate over 4 weeks was shown to be faster with three-species dung beetle assemblages compared to two-species or monocultures of equal biomass in ivermectin-treated rather than parasiticide free control dung (Beynon et al., 2012b). Long-term dung decomposition (36 weeks) was faster with species-rich assemblages regardless of parasiticide contamination. In contrast, the impact of anthelmintics on beetle activity, beyond the immediate point of exposure, has been questioned, if uncontaminated dung becomes available after the point of treatment (Manning et al., 2017a). Furthermore, no significant effect of species richness on multifunctionality was reported in artificial enclosure experiments using a manipulated dung beetle community composed of four *Aphodius* species exposed to ivermectin (Manning et al., 2017b).

Of the organic farms included in this study, there was a positive relationship between the number of years the farm had been organic and the total abundance of dung inhabiting Coleoptera trapped. Additionally, there was a positive relationship between the land area of the organic farms and the dung beetle species richness. This was not the case for conventionally managed farms, and suggests that over time organic practices could have positive effects both on biodiversity and species abundance at the farm level. It must be noted that these correlations are based on a sample size of 11 organic farms, and should therefore be interpreted with caution. Work examining the effects of intensification of agriculture on dung beetle communities in Éire, found species richness, diversity and abundance of *Aphodius* dung beetles to be lower on intensively managed farms (n=4) than registered organic farms that used no ivermectin treatment (n=4) (Hutton and Giller, 2003). A further study comparing conventional (n=8) and organic (n=6) dairy farms, and conservation areas (n=6) in the Netherlands, reported higher insect numbers recovered from twelve 10-day old pats collected from organic farms and conservation areas than conventional farms (Geiger et al., 2010). In addition, farms that participated in agri-environment schemes had a significantly greater abundance of dung beetles in late summer than those that did not participate, suggesting that these management practices, which aim to support biodiversity and improve water, air and soil quality (DAERA, 2010), may have beneficial effects on dung beetle communities over a season.

Conclusions

The work presented here considers the sustained effects of both macrocyclic lactones (MLs) and synthetic pyrethroids (SPs) on dung beetle communities in agricultural landscapes and identifies lower dung beetle species richness and diversity with the use of MLs, and alterations to functional diversity associated with the use of both chemical classes. It is possible that differential impacts between functional groups may account for species of endocoprid (dung dwelling) beetles dominating the community on farms that use parasiticides, and paracoprid (dung burying) beetles becoming less abundant. The changes in functional assemblages seen on farms that use parasiticides have the potential to impair ecosystem multifunctionality and contribute to pasture fouling, disease transmission, reduced pasture fertility and economic loss for farmers (Nichols et al., 2008; Beynon et al., 2015; Sands and Wall, 2016) but further studies are required to resolve these issues at a landscape level.

Conflict of interest

The authors declare that they have no conflicts of interest

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Table 1. Management practices and other variables for each of the beef farms on which cattle dung-baited pitfall trapping was carried out. All study sites were situated in SW England.

Farm	Organic status	Parasiticide use	Treatment frequency (months per year)	Proportion of herd treated	Years since registered organic	Participation in agri-environment scheme	Number of years farmed	Terrain	Grazed area (m^2)	Number head of cattle	Breed	Winter housing	Other livestock
1	Organic	None	-	-	15	Yes	29	Lowland	2.02×10^6	152	Sussex	Yes	Sheep
2	Organic	None	-	-	14	Yes	16	Lowland	0.38×10^6	65	Holstein	Yes	Sheep
3	Organic	None	-	-	11	Yes	15	Hill	1.82×10^6	180	North Devon	No	Sheep
4	Organic	None	-	-	16	No	40	Lowland	0.40×10^6	44	Aberdeen Angus / Devon	Yes	Sheep
5	Organic	None	-	-	17	Yes	22	Lowland	0.21×10^6	24	Shetland	Yes	Sheep
6	Conventional	None	-	-	-	Yes	16	Lowland	0.31×10^6	27	Mixed	Yes	Sheep
7	Conventional	None	-	-	-	No	72	Lowland	0.32×10^6	23	South Devon	No	No
8	Organic	SP	1	0.2	15	Yes	50	Upland	2.23×10^6	200	Mixed	Yes	Sheep
9	Organic	SP	3	1	13	Yes	20	Lowland	1.01×10^6	130	Hereford	Yes	Sheep
10	Organic	SP	4	1	18	Yes	20	Lowland	1.01×10^6	135	South Devon/Red Poll	Yes	Sheep
11	Organic	SP	3	0.2	5	Yes	35	Lowland	0.81×10^6	124	Mixed	Yes	No
12	Organic	SP	2	0.5	18	Yes	40	Lowland	0.81×10^6	160	Mixed	Yes	Dairy cattle
13	Organic	SP	1	1	6	Yes	27	Lowland	0.65×10^6	105	Red Devon	Yes	No
14	Conventional	SP	1	1	-	Yes	16	Upland	0.62×10^6	31	Long Horn	Yes	Sheep
15	Conventional	ML	3	0.6	-	Yes	150	Lowland	3.23×10^6	1500	Mixed	Yes	No
16	Conventional	ML	1	1	-	No	45	Lowland	1.01×10^6	150	Mixed	Yes	Sheep
17	Conventional	ML	1	0.38	-	Yes	7	Lowland	0.49×10^6	80	Aberdeen Angus	Yes	Sheep
18	Conventional	ML	1	0.24	-	No	3	Lowland	0.53×10^6	124	Hereford x	Yes	Sheep
19	Conventional	ML	1	1	-	Yes	40	Lowland	0.26×10^6	95	South Devon	Yes	No

20	Conventional	ML	4	1	-	Yes	30	Hill	1.01×10^6	350	Mixed	Yes	Sheep
21	Conventional	ML	1	1	-	No	75	Lowland	1.01×10^6	50	Limousin x	Yes	Sheep
22	Conventional	ML	1	0.65	-	No	80	Hill	0.24×10^6	92	Blonde x	Yes	No
23	Conventional	ML	2	1	-	No	9	Lowland	1.26×10^6	136	British Blue x	Yes	Sheep

SP = synthetic pyrethroid, ML = macrocyclic lactone, None = no parasiticide used.

Table 2. Mean abundance (±SE) of beetle species identified from farms that used no parasiticides (None) (n=7), synthetic pyrethroids only (SP) (n=7) or macrocyclic lactones only (ML) (n=9), and their percentages across farm types.

					Mean abundance (±SE)			Percentage across sites		
Family	Subfamily	Genus	Subgenus	Species	None	SP	ML	None	SP	ML
Geotrupidae		*Geotrupes*		*spiniger*	2.17 ± 1.47	1.17 ± 0.68	0.43 ± 0.36	57.6	31.0	11.4
Scarabaeidae	Scarabaeinae	*Onthophagus*	*Palaeonthophagus*	*coenobita*	127.92 ± 114.53	8.58 ± 3.81	2.12 ± 1.25	92.3	6.2	1.5
		Onthophagus	*Palaeonthophagus*	*similis*	7.00 ± 3.17	29.91 ± 8.79	1.86 ± 1.23	18.1	77.1	4.8
		Onthophagus	*Palaeonthophagus*	*joannae*	0.08 ± 0.08	-	0.07 ± 0.07	53.3	0.0	46.7
		Onthophagus	*Palaeonthophagus*	*fracticornis*	0.08 ± 0.08	-	-	100.0	0.0	0.0
	Aphodiinae	*Aphodius*	*Acrossus*	*rufipes*	158.42 ± 62.80	212.83 ± 83.22	276.93 ± 81.59	24.4	32.8	42.7
		Aphodius	*Colobopterus*	*erraticus*	16.10 ± 1.68	9.17 ± 5.63	4.36 ± 2.13	54.3	30.9	14.7
		Aphodius	*Acrossus*	*depressus*	5.42 ± 3.43	1.83 ± 0.82	0.21 ± 0.11	72.7	24.5	2.8
		Aphodius	*Aphodius*	*fimetarius*	4.42 ± 2.38	5.92 ± 4.40	0.86 ± 0.44	39.5	52.9	7.7
		Aphodius	*Agrilinus*	*rufus*	4.42 ± 1.68	8.58 ± 3.80	16.29 ± 8.42	15.1	29.3	55.6
		Aphodius	*Teuchestes*	*fossor*	2.50 ± 1.97	2.58 ± 1.26	4.50 ± 3.36	26.1	26.9	47.0
		Aphodius	*Esymus*	*pusillus*	1.08 ± 1.08	0.92 ± 0.57	0.79 ± 0.37	37.2	31.4	31.4
		Aphodius	*Agrilinus*	*ater*	0.75 ± 0.51	1.92 ± 1.02	0.36 ± 0.20	24.8	63.4	11.9
		Aphodius	*Melinopterus*	*prodromus*	0.42 ± 0.42	0.42 ± 0.23	-	50.0	50.0	0.0
		Aphodius	*Rhodaphodius*	*foetens*	0.33 ± 0.33	0.42 ± 0.42	-	44.0	56.0	0.0
		Aphodius	*Aphodius*	*pedellus*	0.33 ± 0.19	0.08 ± 0.08	0.71 ± 0.57	29.5	7.1	63.4
		Aphodius	*Volinus*	*sticticus*	0.17 ± 0.17	1.00 ± 0.61	0.07 ± 0.07	13.7	80.6	5.6
		Aphodius	*Otophorus*	*haemorrhoidalis*	0.08 ± 0.08	0.17 ± 0.17	-	32.0	68.0	0.0
		Aphodius	*Nimbus*	*contaminatus*	0.08 ± 0.08	-	-	100.0	0.0	0.0
		Aphodius	*Melinopterus*	*sphacelatus*	-	0.08 ± 0.08	2.79 ± 2.71	0.0	2.8	97.2

	Aphodius	*Aphodius*	*foetidus*	-	0.33 ± 0.33	-	0.0	100.0	0.0
	Aphodius	*Melinopterus*	*punctatosulcatus*	-	-	0.21 ± 0.21	0.0	0.0	100.0
	Aphodius	*Planolinus*	*borealis*	-	0.08 ± 0.08	-	0.0	100.0	0.0
	Aphodius	*Acrossus*	*luridus*	-	-	0.07 ± 0.07	0.0	0.0	100.0
Hydrophilidae	*Sphaeridium*		*lunatum*	71.83 ± 16.04	105.25 ± 28.60	48.21 ± 20.41	31.9	46.7	21.4
	Sphaeridium		*scarabaeoides*	66.75 ± 14.13	96.17 ± 27.43	56.07 ± 23.31	30.5	43.9	25.6
	Sphaeridium		*bipustulatum*	18.83 ± 3.63	20.58 ± 4.34	11.07 ±3.57	37.3	40.8	21.9
	Cercyon		spp.	294.59 ± 53.20	448.75 ± 113.78	421.43 ± 163.92	25.3	38.5	36.2
	Megasternum		*obscurum*	0.17 ± 0.11	0.17 ± 0.11	0.07 ± 0.07	41.5	41.5	17.1
Histeridae	*Margarinotus*		*carbonarius*	1.75 ± 0.70	3.42 ± 1.68	2.21 ± 1.09	23.7	46.3	29.9
	Margarinotus		*purpurescens*	0.17 ± 0.11	0.58 ± 0.40	0.29 ± 0.16	16.3	55.8	27.9
Staphylinidae				214.75 ± 32.28	258.83 ± 52.45	280.21 ± 59.80	28.5	34.3	37.2